THE INFLUENCE OF COLOR UPON MENTAL AND MOTOR EFFICIENCY*

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I. PROBLEM

The problem of the study may be put as follows: Do different hues and brightnesses of general illumination have (*aside from* the obvious importance of these factors in conditioning the effective functioning of the visual apparatus) any specific influence upon mental or motor efficiency? The subject is obviously of great practical importance. If adequate lighting in factory or office tends to stimulate activity and increase the amount of work done, as well as to aid in visual efficiency, the matter is of no slight moment from a business point of view. If, as is often supposed, an office or

* From the Psychological Laboratory of Harvard University. The paper is a summary of the writer's thesis for the doctorate, which was presented in April, 1917, but which, because of pressure of other work, it has not been possible until now (October, 1919) to condense and arrange for publication.

school-room furnished in red has a distinctive effect, upon mood and upon sustained capacity for work, as compared with a room furnished in light green or buff, then the definite demonstration of that fact would be of decided practical value. The aim of the present study was to investigate experimentally, in the laboratory, this question as to the effect of brightness and of hue upon mental and physical work.

II. Previous Work Bearing Upon the Subject

As thus conceived, the study differed, in certain important particulars, from other investigations in this general field. In the first place, color combinations were not considered. In the second place, large surfaces, involving the subject's entire field of vision, were used, not small stimulus-areas (usually the subject worked in a room illuminated solely by a light of the desired brightness or hue). In the third place, the interest was in objective measurements of mental work and neuro-muscular tone, not in introspective reports. Finally, as has already been mentioned, the study was not concerned with the effects of hue or brightness upon visual acuity or ocular fatigue; any such effects were carefully avoided. Previous studies in the aesthetics of color have, however, most important bearings upon the writer's problem. A consideration of these previous studies may be conveniently taken up under three heads, according as the work was (*a*) introspective or observational, (*b*) experimental, or (*c*) analytical and critical.

(*a*) *Introspective and Observational Studies.* The earlier work treats rather of the artistic values of the different colors than of the narrower problem of the relation of color to affection. It is impossible in brief space to summarize the mass of this material. It may be said, shortly, that introspective consideration of the matter seemed to indicate that each color conditioned a specific emotional and affective response of great richness.

Goethe's "Farbenlehre" is the most important early treatment. There are "active" and "passive" colors. The hues from yellow through red are exciting, lively, arousing, the climax being reached in the red. From blue back to red is the minus or passive side; and at green is a balance of arousing and depressing influence which gives a feeling of peace and comfort. There is thus a complex and intimate relation between color and affection.[6] Such theories find their best known and most systematic formulation in Wundt.[40]

Anecdotal data with regard to color,[38] anthropological observations,[15] and studies in the history of art,[16] may also

contribute to the problem. Savages, and also many animals, show a marked fondness for bright colors and for shiny, brilliant objects. As evidences of the same tendency in civilized man may be cited the fondness for diamonds and other gems, for fire-works, for lacquer, gilding, boot-blacking, and the adoption of shiny metal for money.[15] Among the hues red has an outstanding position; the power of red to attract attention and arouse action, in both men and animals, is made much of.[10] However, there may be striking differences in the affective character of a hue, from one locality to another or one period to another. Thus yellow was in classical times a favorite color, and is now least liked.[11]

(*b*) *Experimental Studies.* Midway between such observational studies and the laboratory research comes a mass of more or less roughly controlled investigations, mostly with children, of which the monographs of Miss Shinn,[34] Mrs. Moore,[26] Preyer,[29] and Major,[24] and the papers of Winch,[39] Wells,[37] Jastrow,[18] may be mentioned. The gist of the results may be put in a sentence. There is an early fondness for bright colors, decreasing with age; an especially rapid dropping back of yellow, ending in least liking; in general blue and red are liked best.

The laboratory work may be summarized quite as briefly. There is an almost absurd difference of opinion among many of the experimenters as to the affective value of the various hues. And experimental studies of special problems in the aesthetics of color show little more (relevant to the present problem) than the extreme complexity of many reactions to color, and the multitude of factors which may play a part.

Cohn[7] states that his is the first experimental study of the aesthetics of color. He placed his subjects in a dark chamber, and used for stimuli small gelatine plates; the illumination was by daylight. He found, briefly, that saturated colors were preferred, but that as between different hues of equal saturation the choice was a matter of individual idiosyncrasy. On the whole, yellow was least liked; but the data are not considered adequate for any generalization in the matter. Cohn had seven subjects, and worked by the method of paired comparisons. Major[25] used colored papers, and a different method. He had four subjects. Neither antipathy for yellow nor preference for saturation was discovered. Cohn[8] thereupon experimented further, and confirmed his previous results as to saturation. Miss Baker[2] found the warm end of the spectrum most pleasant. Fernberger[13] found relative dislike for yellow and yellow-green. Miss Washburn[36] found that thirty-five college girls liked tints best, shades next, and saturated colors least. Blue was preferred, of the hues.

Some few papers have appeared which try to deal experimentally with the apperceptive elements in color attitudes. Thus Bullough[4] worked on the question of the apparent heaviness of colors. He concluded that a color looks light or heavy according to its luminosity,

stressing this element rather than any association of dark and low objects, or analogous explanations. Pierce[28] found that bright colors "weigh" more than dark ones in making up an ornamental balance; he explains this on the basis of the "action theory" and greater demand of the bright objects for eye-movements. Quantz[30] and Larguier des Bancels[20] agree that color affects the apparent size of objects. Thus red surfaces look larger than equal blue ones. But no satisfactory explanation is offered.

Investigation by the method of expression has led to similar contradictory results. Or rather, it may be said, that the best work of this type has given negative findings.

First to be mentioned of such studies should be Féré,[12] who, while experimenting with hysterics, found the most remarkable differential reactions to different tones, different tastes, different smells, and finally to different colors. If the patient was shown a red light there was an increase in pulse, a disturbance of breathing, a distinct increase in muscular strength as shown by the dynamometer. And, since he considered his neurotics to exihibit in marked degree what was true in kind of normal individuals, Féré concluded that, with normal individuals also, red had a dynamogenic effect.* A Leipzig study by Stefanescu-Goanga[35] comes to a somewhat similar conclusion. Striking results, giving confirmation of the Wundtian theory of the correlation of bodily changes and tri-dimensional feeling, were obtained. However, McDougall[23] found no specific effect of either hue or brightness upon reaction time.† Angell and Thompson[1] found no evidence of any specific association between organic changes and various visual stimuli. Shepherd's very careful work also failed to yield any evidence of such a connection.[33]

(*c*) *Analytical and Critical Studies.* The great importance of social influences, of literary and religious symbolism, and of language, in developing affective reactions to color is the one point constantly stressed by the more critical writers. That other than intrinsic values are important is apparent from the way color preferences change in art, and even with famous artists during their lifetimes. The effect of a color may be totally changed by slight change of circumstances. And such affective toning, though the result of previous associations, need by no means show any trace of those associations. The ideas and feelings have grown together, amalga-

* Féré's work is extremely interesting. But surely these hysterics, who present as perhaps the fundamental symptom an extreme suggestibility, are exactly the persons who would respond most completely to the many subtle suggestions of language, art, and custom, which will shortly be mentioned (not to speak of possible unconscious suggestion from Féré himself). For the distinguishing of a true dynamogenesis, as distinct from the effect of such influences, no subjects could be less reliable.

† Prof. E. B. Holt has told the writer of a very similar study, made by Holt, with completely negative results. The average times, with the different hues, were almost perfectly identical.

mated their effects, until these are indistinguishable from innate hereditary attitudes.

So Müller-Freienfels[27] emphasizes the extent to which a color may be given an affective value simply by its name, as blood-red, or violet, or lilac, or orange, or lavender. The red-furnished room mentioned by Miss Calinich[6] is also of some interest. If the room was warm the reds seemed bright, lively, cheerful, warm and enlivening. But if the room was cold these same reds were dreary, depressing, with a peculiar, dead, chill effect.

The odd artistic career of yellow may also be instanced to show the extent to which even very special and artificial circumstances may have a profound effect upon the esteem with which a color is regarded. Yellow was a favorite color in classical times, and is now in the East. But there is, as has already been mentioned, some evidence to indicate that for the average European it is the color least liked. The change is (according to Havelock Ellis) due to the Church; the early church authorities looked upon the color with disfavor because of its association with pagan festivals and licentiousness, and succeeded in building up about the hue a group of symbolisms and associations of the most unpleasant character.[11]

Previous work bearing upon the writer's problem may, then, be briefly summarized as follows. (*a*) Introspective and observational studies show colors, as they appear in everyday experience, to have a marvelous richness and complexity of affective significance. There is the suggestion that color may be a conditioning factor of distinct importance in influencing the efficiency of mental work. (*b*) Laboratory experimentation for the most part fails to find any constant relationship between color and either introspective evaluation or organic reaction. (*c*) Analytical and critical studies emphasize the importance of artistic conventions, symbolism, language, and everyday association of certain colors to other sensations affectively toned, in giving an emotional connotation to the hues and brightnesses.

It would then seem reasonable to conclude that if color *does* have any fundamental physiological effect, such as would influence mental and motor efficiency, the connection must be of a very general and elementary nature; brightness may stimulate, or red irritate and distract, but more specific effects are hardly to be expected. It is some such relationship as this, between illumination and mental work, which is sought in the writer's experimentation.

III. Experimental Results

A. *Preliminary Experimental Definition of the Problem*

This experimentation began with a brief preliminary investigation, of an exploratory character, in which large sheets of colored paper were used. Nothing more need be said about

the method than that the subject was seated comfortably at a table, with a large sheet of colored paper arranged in front of him so as to be almost the only object within his field of vision. While in this situation, thus dominated visually by the color, the subject was asked to introspect, and to do certain tests. Nothing more was done with the tests than to make trial of them. But the introspection yielded some points of interest. In the first place, the finish and texture of the paper appeared exceedingly important, especially so far as pleasantness and hold on the attention were concerned; the "energizing" or "stimulating" effect seemed more dependent on the hue. Where there is a shimmer, or where the light falls across a rough finish so as to emphasize the roughnesses, the result is peculiarly disagreeable. Any smudges on the paper were sure to be noticed, and were likely to play a part in the association; thus the dominant feeling of one subject for an orange was uneasiness centering in the kinaesthesis of a desire to reach out and smooth an unevenness in the paper. In the second place, the introspection suggested that the special affective values often assigned to such colors as lavender, purple, orange might be due to other causes than the hue itself. Such colors are unusual, and so attract and hold the attention; because they are unusual, what associations they have are definite and concrete, and give great vividness. With repetition, however, these factors usually drop out, and the color is ranked along with the primaries, as more or less bright, stimulating, depressing; is sometimes liked merely because it has in it more or less yellow or blue. Finally, individual differences, both in the evaluation of the different colors and in the general type of reaction to them, were marked. In fact all of the types mentioned by Bullough[5] and Bradford,[3] with variations, appeared at one time or another, from crude sensory effect to complex personalizing attitude. The reports made excellent evidence for the complexity of responses to color mentioned in the preceding section.

Thus one subject reported of a striking reddish purple that he "liked the color. But there was no special effect, aside from the pleasantness; otherwise it was neutral." And at the end of the color period it was "about as before. No great fatigue. The affective value was somewhat less, but fairly durable." Very different are the descriptions of another man, who says of a rough-finished yellow that it is "heavy, like an overcoat; queer feeling; not pleasant, not unpleasant. Impression that color is deep, and thick. Kinaesthetic sensation in finger tips as result of thickness. Heaviness seems referred largely to texture." A light yellow green is "very pleasant, a buoyant feeling." Another day this same subject finds the same color "depressing; the color of grass when it's dying."

More explicitly associative is a report on yellow. "A slight greenish effect; brought up idea of grapefruit tree at the Exposition and emotions going with that trip. Now wonders how got green; had seen stripes of green." An orange was liked; but then, with a thought of the war, came an idea of this as the color of bloody water, and a feeling of repugnance.

Different still in type of response is the characterization of a red as "too aggressive; it pushes itself upon you, won't let you alone, rude. I don't like it."

Enough has already been said to suggest the unsatisfactoriness of colored papers as stimulus areas. In the first place, no adequate control of brightness was possible; but such control was clearly essential if an adequate analysis of the problem was to be made. In the second place, the texture of the papers, and any wrinkles or spots, played too important a part in the subject's reaction to make adequate control possible. And in the third place it was not feasible to arrange the experimental setting, with colored papers, as was necessary for the problem. The problem was to determine the effect of color, as a dominant but unobtrusive and natural element in a situation, on mental and physiological processes. If paper were to be used little less than to have the walls covered with it would suffice. Under the circumstances, trial was naturally made of colored lights.

With regard to the preliminary work with colored lights, nothing more need be said than that it was of the same general character as the systematic experimentation to be described shortly. Work with the colored lights was begun in March (1915) and the remainder of that school year was spent simply in trial of various tests, light screens, and so on. The results to be described in the next section were, therefore, obtained with methods which had been carefully elaborated in this trial series.

The preliminary work served chiefly to develop methods and setting and to make trial of tests. The introspective material may be summarized as follows. (1) Affective reaction to colors is highly variable, both from individual to individual, and from week to week with the same individual. No hue, except perhaps red, may be said to show characteristics of any constancy. (2) The reaction is very easily modified, or often wholly changed, by (*a*) subjective factors such as general condition, mood, constellation of ideas, or chance association, and by (*b*) incidental objective factors such as unevennesses in the colored surface, and especially the texture of this surface and the way in which the light is reflected from it (softly, or with a shimmer, glint, or glare). (3)

The reaction may be of all degrees of complexity, from simple sensory effect to elaborate associative development or subtle personalizing attitude.

Introspective treatment of the subject will be returned to, briefly, later.

B. *General Experimental Setting and Method*

The experimental setting developed during the last part of the preliminary work was continued, essentially unchanged, throughout the remainder of the study. It may be described as follows. One end of a long narrow dark room was shut off by a heavy black curtain, making a smaller room about 9x6 ft. Backed up against the curtain was a table three by five. Behind this, that is, facing the curtain and with his back to the end wall of the room, sat the subject. The table was covered with heavy unglazed drawing paper. Over the center of the table, and 26 in. above its surface, was the light-box (8 by 10 by 12 in.), held by a frame-work from the ceiling. This contained four 100 c. p. Mazdas. In the base of the box were slots, where the colored plates could be slipped in. The light box was dead black outside, but lined with metal to reflect the light downward; on the side of the box next to the subject was a black pasteboard drop hanging just low enough so that none of the direct light came into his face. At one end of the table, and dropping down almost to its surface, was the cord, with its glove finger, for the tapping test. Well off to the other side was the small block of wood with the two keys, for the reaction test; this was hooded over with a piece of the white drawing paper, to make it as unobtrusive as possible. The glove finger and the reaction key block were the only pieces of apparatus visible to the subject.

As has been said, none of the direct light came into the subject's face. The light shone directly, however, on almost the whole surface of the table, but very little beyond this. The situation was thus not at all uncomfortable for the subject. He sat easily at the table; the light came from a position not uncommon in ordinary lighting arrangements. There was no shimmer, glint, or glare, from the unglazed paper, only a soft, diffused, indirect illumination. And aside from this there was only the hardly-to-be-seen blackness of walls and curtain. This was the situation when the test lights were burning; when the "normal" light (a 16 c. p. Mazda fastened to the light-box on the side away from the subject) was on, between tests, the situation was very little changed. The lighting was still indirect, came from the same position approximately, and was of roughly the same brightness as the colors used.

On the other side of the curtain, and against the wall, was the experimenter's table. On this were the various recording devices, the theatre dimmer for equating the brightnesses of the colored lights, the time keys, and so on. Here also was the double-throw switch, arranged to throw on the test lights at the same instant that the "normal" was thrown off (and the reverse), so that there should be no period of darkness, or irregular interval, between the two stimuli. The experimenter's table was lit by a four candle-power lamp in a hooded "goose-neck" holder; it was wholly invisible to the subject behind his heavy curtain.

From now on the study consisted of two separate pieces of experimentation, making use, however, of the same tests, the same methods and the same setting; the "hue series" was planned to discover any possible effects of hue, independent of brightness, and the "brightness series" to isolate any influence of brightness, upon mental work. The plates used in the hue series were complementary blue, pure green, red. The stimulus lights were equated for brightness (by episcotister) in terms of the darkest, blue; to do this a theatre dimmer was used to shift the illuminating power of the lamps according to the absorption of the different plates.* The illumination, on the top of the table under the lamps, was about seven candle-meters. The brightness series with which most work was done was also a three-unit series. The dim light was obtained by stepping down the current with the dimmer and putting in the white screen; it gave an illumination on the surface of the table of about one candle-meter. The medium light was given by a single 32 c. p. Mazda, placed in among the larger lamps in the box so as to give the same distribution of light, and thrown in by double-throw switch after the "normal" in the same way. The bright light finally settled upon was the full power of the four 100 c. p. Mazdas.

For one semester, however, a five-hue and a four-brightness series were run. The five-hue series consisted of the hues above mentioned *plus* yellow and white. For white a special plate, a double thickness of "pot-opal" glass, was made; at the above-mentioned brightness the light through this was found to be almost pure physiological white. The four-brightness series consisted of the same two extremes as were used in the three-brightness series, but with the white of the hue series, and a medium bright light made by the white plate with the full power of the four Mazdas behind it, in place of the 32 c. p. "medium."

Three possible criticisms of this choice of stimuli remain for brief discussion. In the first place, it may be said that an effort should have been made to obtain monochromatic colors for the hue series. To

* The writer is indebted to Dr. L. T. Troland for the equating of the brightnesses, and for the rough analysis of the lights here given.

this it may be replied shortly that the problem of the study was essentially a problem in applied psychology, and that what was sought was the effect of colors such as might be used in actual schemes of illumination or decoration. The important requirement was that the lights should be seen by the subjects as red, green, and blue, of a not unusual composition or saturation, and that the saturations should be approximately equal. The lights were, as a matter of fact, almost invariably judged by the subject as simply blue, green, or red without admixture of other hues; and they were considered about equally saturated (the yellow was dropped partly because less saturated). Nothing more seemed essential. Monochromatic light, supposing it could have been obtained for use over such areas, would have been a highly artificial form of stimulus much less relevant to the practical problem.

It may be objected, in the second place, that more hues (and more brightnesses) should have been used. The difficulty was mainly a matter of method, and of experimental practicability. Most of the subjects came to the experiment only once a week, for a 50 min. period; five or six colors meant only seven or eight minutes with each. The problem, however, was to determine, not the effect of the presentation of the color, but the influence of its continued presence as part of a work situation. Longer periods were thus clearly necessary. So it seemed best, for this and various other reasons, to limit the experimentation to intensive study of three hues, and three brightnesses. Practically all the previous work (not to mention the writer's own preliminary study) indicated the colors at the two ends of the spectrum as the hues most diverse, fundamentally, in their effects. It seemed reasonable to suppose, therefore, that an intensive study of red, of green, and of blue would indicate with fair adequacy the direction and amount of the influence, if any were to be found, and give the best evidence for negative conclusions in case the results were negative.

In the third place, criticism might be made of the "very bright" light of the brightness series, as too strong, possibly so bright as to trouble the eyes, and so introduce factors not relevant to the problem. The writer expected such difficulties. And he was much surprised to find, after extended trial with all the subjects, that in most instances this bright light was the most pleasant of the series! The subject received only indirect, diffused light; there was no glint, glare, or other unpleasant distribution. Under these circumstances this light was usually introspected upon as stimulating, cheering, very pleasant. And anything less bright failed to give the desired distinctness from the "medium" light.

As has already been intimated, most of the work was done with three hues, or three brightnesses, to the hour. This permitted 12 to 15 min. with each color, with intermissions between colors of about 4 min. The colors were given in a definite routine; if, for instance, subject "A" was given on the first day red first, green next and blue last, then for his next hour (the following week) he was given green, blue, red, and the third hour blue, red, green. After three hours, then, each color had appeared once in each position in the hour. This made up a unit, within which the various factors of the work curve (fatigue, practice, and so on) were evenly

distributed among the colors. The next group of three would begin red, blue, green: in this way every possible order was tried. Between colors the "normal" light already mentioned illuminated the subject's room.

The number of subjects varied from one semester to another; usually there were six or eight, and two came twice a week, the rest once. Subjects who came twice a week were given one hour with the hue, and the other hour with the brightness series; the other subjects were divided up equally between the two series. Regular hours were assigned; the experimentation was done in the morning, in hour periods, between nine and one. The subjects were all trained observers, and familiar with laboratory methods and technique.

In the entire study (including the preliminary work) twenty-six persons at one time or another acted as subjects. One was a professor of psychology; seventeen were graduate students with experience in research. Eight were Harvard undergraduates doing advanced work in psychology; three of these were carrying on independent research. Three of the graduate students were women. It should, perhaps, be added that the study was made during the university years 1914-1915, 1915-1916, and 1916-1917 to the first of March.

Much difficulty was found in securing satisfactory tests, because of the fact that the purpose of the experiment prevented the employment of any test requiring use of the eyes; the purpose was not to study visual acuity with lights of different colors, or the effects of eye strain in dim light on mental work, but to discover whether *apart from such factors* different hues and different brightness had any influence on general neural tone and mental efficiency. The vast majority of tests previously used in such comparative studies (studies of the effects of drugs, for instance) were thus barred from the writer's experimentation. And much time was spent in simply developing tests which would meet these special requirements. The tests finally adopted will be described in detail later, along with the presentation of the results obtained. A large number of other tests (as dynamometer measurements, maximum speed in tapping, several forms of memory test) were tried, but found unsatisfactory and rejected.

The test routine varied, of couse, with the tests employed. The first of the work was done with the following tests, and in the following order. First, under the normal light, the subject tapped for 30 sec. (this was not the usual tapping test, but a tapping "at most comfortable rate," as will be described later). Then the normal light was thrown off and the test color on; the tapping, however, continued for another 45 sec. Introspection was now called for. After this, the multiplication was given, then the pressure test, then the memorizing. Forty-five sec. more of tapping followed this. Finally, introspection

was asked as to any change in the influence of the color from that reported when the light first appeared. The normal light was now thrown in, and the subject rested for 4 min. while the experimenter changed the colored plates, adjusted the theatre dimmer, slipped new smoked papers on the kymograph drums and adjusted the recording apparatus. Then the same programme was repeated with the other two hues. Introspection was called for only during the first two or three weeks at the beginning and end of a half year's work; for the greater part of the time the work was wholly objective.

This general arrangement was adhered to throughout the experimentation. As sufficient data were accumulated with a test it was dropped, and a new test substituted; the routine, however, remained essentially the same. Work in the color series and in the brightness series was also throughout the same; there were the same conditions, the same tests, and the same routine; so that the two series were in all respects strictly comparable.

Every half year saw a change in programme of some sort. With a new test three hours of practice were allowed, as a rule, before results were used. Data from twelve hours following this were the aim. This was not always possible, however. By the methods used, the results with a given color, in a given hour, and on a given test, obtained their significance from comparison with the results, on that test, under *all* the other lights. If now, reaction times under green were lengthened by the sound of the bell at the end of the hour then all the results, with the other colors as well, were warped in their significance. So the rule was made that no results from any hour which was interrupted, in any way, on any test, should be included. A large amount of material was, of course, eliminated by this rule; but the eliminations seemed necessary, if the subtle effects sought were not to be buried completely under such chance variations. The endeavor was also made to obtain, in each series, results from at least six individuals, on each test. This was, again, not always possible (or worth while) but was done in the majority of cases.

A word remains to be said regarding the handling and interpretation of the data. In the investigation of any such subtle influences as were being sought chance variations in the results are certain to be large, and differences (if any) due to the factors studied, small. Satisfactory interpretation and evaluation of the data are thus extremely difficult. The situation is, essentially, too complex to make possible any summary of the consistency of the findings, which could be treated statistically. Instead, a judgment upon the reliability of the data has been attempted, based upon three related, but distinct, sets of facts: (1) the consistency of the results obtained from each subject, on each single test; (2) the degree of agreement among different subjects on each test; and (3) the consistency of the results from test to test with each subject (a correlative consideration here being, of course, the consistency of the group from test to test). Any final numerical statement of the reliability of the findings must, of necessity, be partial and inadequate. Instead, an attempt has been

made to bring all the facts, considered from these three points of view, together in a judgment as to the probable meaning of the data.

The writer is not at all sure, now (1919), that a more determinate and decisive statistical treatment of the material would not have been possible. But, in defence of the procedure adopted, it may be pointed out that practically all the well-known studies having similar statistical problems have been quite as indecisive in their statistical statement. Most similar, in the statistical problem presented, are studies of the effects of drugs, of which the monographs of Hollingworth[17] and Dodge[9] may be cited. And it might be pointed out in this connection that, so far as difficulties of control and analysis are concerned, study of the effect of only three colors, in one short hour, is not a little analogous to an attempt to study the effect of three drugs in that brief space of time. The problem was not an easy one, and abounded in unusual difficulties of analysis and statistical treatment.

The methods used will be discussed in more detail in considering the results obtained with each test.

C. *Results*

1. *The Effect of Color upon Rate of Rhythmic Movement of the Finger.* This test was planned to give an indication of any change in neuro-muscular tone and tendency to movement. It was, essentially, an ergograph with minimal resistance. Clamped to the end of the table was a rod which reached obliquely in over the table top. The end was about 15 in. above the table, and the same distance in from the table end. To the rod was fastened a pulley. Through this ran a silk cord, to which was sewed a glove finger. The subject put his left fore-finger in the glove, and rested his arm easily on a support which kept his finger free above the surface of the table. The test consisted simply in moving the finger up and down with a tapping movement. The white silk cord ran over to the experimenters' table, where it was fastened to a marker which wrote on a smoked drum, and to the resistance, a single piece of ordinary rubber band. The subject was told to tap at an easy, comfortable rate, which could be kept up without fatigue during the minute tapping period; to find the rate which was most natural and comfortable for him; then to forget all about the test, letting the movement go on automatically. There was a specific caution against any effort at speed.

The test should, the writer felt, be quite highly sensitive to any energizing or stimulating effect the colors might have. If red *did* excite, or a dim light subdue, this ought to show easily in such a half-conscious rhythmic activity as this simple movement, up and down, of the finger. But there were other advantages. Practice effects were unimportant; there was no learning; there should be nothing of those

wide variations likely to appear when there is any requirement of maximal effort.

The place of the test in the routine has already been described. The tapping was begun 30 sec. before the stimulus light was turned on, and was continued for 45 sec. after this. The other tests were then given. And finally, just before the stimulus light was turned off, there was tapping again for another 45 sec. Time was marked off in 15 sec. units. The results were handled in terms of these units. The number of taps in the first two quarter-minutes under the normal light were averaged to give the average normal for the period. The number of taps in each one of the six quarter-minutes under the stimulus light were then scored so much *plus* or *minus* from this normal for the period. And the difference between the variation from its normal produced by red, and the variation from *its* normal produced by the blue, gave the difference in effect of these two colors.

This final figure, it should be emphasized, was almost wholly free from the influence of constant errors. With some of the tests, systematic variation through the hour, due chiefly to difficulty in getting started with the work, and to fatigue in the last period, were considerable. However, with this arrangement of the tapping, the normal, for each period, just preceded the color period itself. If red came last in the hour on a given day, its normal came near the last too; the normal took account of the variations through the hour (as well as of the daily variations), and none of these irrelevant factors got itself into the results.

In handling the results the number of taps, in each 15 sec. under the color, was first scored as so much *plus* or *minus* from the average number of taps per 15 sec. under the normal light, as has been just described. The variations for the first three quarter-minutes under the color were then added, giving the total variation for the first 45 sec.; and the variations for the last three quarter-minutes also added. For instance, suppose the number of taps per 15 sec. ran as follows:

	Green	
normal	first 45 sec.	last 45 sec.
17 15	16 17 19 (other tests)	17 19 20

This would be scored

16	0 1 3 (4)	1 3 4 (8)

To obtain the final percentage statement, the average normal was multiplied by three, to give the average normal for 45 sec. and the succeeding variations per 45 sec. stated as per cents of this. The above record would thus become

		Green	
	normal	first 45 sec.	second 45 sec.
	48	4	8
and in per cents	48	8%	17%

This could, of course, have been done less elaborately by running a normal of 45 sec. instead of 30 sec. But since the work was begun with a shorter normal it was so continued, and the above method of handling used.

TABLE I

TAPPING RATES: IN TERMS OF % VARIATION FROM "NORMAL"

Four Brightness Series

Sub.	Av. Nor. 45"	I 1st 45", av.	I 1st 45", m.v.	I Last av.	I Last m.v.	II 1st 45", av.	II 1st 45", m.v.	II Last av.	II Last m.v.	III 1st 45", av.	III 1st 45", m.v.	III Last av.	III Last m.v.	IV 1st 45", av.	IV 1st 45", m.v.	IV Last av.	IV Last m.v.
And.....	46	5	6	5	11	— 2	4	0	10	— 3	6	—1	11	2	10	— 6	10
Dav.....	55	—2	3	13	5	1	3	3	7	0	2	2	11	2	4	1	9
Fin.....	49	—8	6	—6	9	—12	11	—1	10	— 5	3	—2	4	—12	6	—11	10
Kal.....	102	7	6	12	14	5	7	10	13	— 2	7	3	20	—11	9	— 5	20
Average ...		.5	5	6	10	— 2	6	3	10	—2.5	4	.5	11	— 5	7	— 5	12

(Ten hours each subject.)

Three Brightness Series

Sub.	Av. Nor.	I 1st 45" av.	I 1st 45" m.v.	I Last av.	I Last m.v.	II 1st 45" av.	II 1st 45" mv.	II Last av.	II Last m.v.	III 1st 45", av.	III 1st 45", m.v.	III Last av.	III Last m.v.
And.....	62	16	7	18	12	2	5	13	9	0	8	5	9
Cur.....	68	4	5	9	6	6	3	2	8	2	3	11	12
Dav.....	77	7	8	9	4	0	2	6	10	7	10	4	7
Woolb.....	51	1	5	0	7	3	3	—4	8	0	3	— 7	10
Mor.....	124	6	7	12	8	11	10	16	11	7	5	18	13
Average.....	...	7	6	10	7	4	5	7	9	3	6	6	10

(For each subject in order the hours were 20, 10, 8, 9, 9.)

TABTE I—*Continued*

Five Hue Series

Subj.	Av. N.	Red av.	Red m.v.	Red av.	Red m.v.	Yellow av.	Yellow m.v.	Yellow av.	Yellow m.v	Green av.	Green m.v.	Green av.	Green m.v.	Blue av.	Blue m.v.	Blue av.	Blue m.v.	White av.	White m.v.	White av.	White m.v.
Br	93	2	4	8	3	2	3	4	2	—2	3	0	6	2	2	0	3	—2	2	5	5
Ch	84	—3	6	6	9	0	6	5	2	—2	3	2	5	1	6	2	7	0	2	10	4
Da	57	0	5	9	8	0	5	1	7	2	2	12	6	0	4	1	8	—1	3	0	7
Ohl	73	3	4	6	4	3	7	0	6	2	4	3	4	0	5	3	4	3	5	1	7
La	109	—2	4	7	7	2	3	10	5	0	2	10	6	1	4	4	4	—1	3	4	6
Average	...	0	5	7	6	1	5	4	4	0	3	5	5	1	4	2	5	0	3	4	6

(Ten hours each subject.)

Three Hue Series

Subj.	Av. N.	Red av.	Red m.v.	Red av.	Red m.v.	Green av.	Green m.v.	Green av.	Green m.v.	Blue av.	Blue m.v.	Blue av.	Blue m.v.
Allp	147	6	4	4	7	6	3	6	7	3	6	2	6
La	107	2	4	6	6	1	3	4	6	1	2	9	9
Bul	44	3	4	9	8	2	5	1	12	3	4	6	8
Br	148	3	2	5	3	—2	2	—1	3	—1	3	3	3
Ch	106	3	4	2	14	0	3	12	8	0	3	4	12
Wo	49	—2	2	—6	11	1	3	1	9	0	4	1	7
Sp	60	10	.	1	14	1.5	12	6	10	0	4	9	6
Average	...	4	3	3	9	1	4	4	8	1	4	5	7

(Twelve hours three subjects, nine hours four subjects.)

The m. v. after the group average is the average of the m. v.'s, not the m. v. of the averages. In handling the per cents, fractions of one per cent were read as the nearest whole number.

The results for the brightness series are given in the following table (Table I). They are stated, as has just been described, as per cent variation, from average under normal light for 45 sec., for 45 sec. under the color. The first series was run with four lights, bright, moderately bright, medium and dim. In this series were four subjects; the number of hours for each was ten. In the second series three brightnesses were used; the first and the last were the same as in the first series, but in place of the moderately bright and medium light a new medium, the 32 c. p. Mazda, was substituted. In this series were five subjects, two of whom had also been in the previous series. The number of hours with one subject was twenty, with one ten, with one eight, and with two nine.

The results may be summarized as follows. Of seven subjects five, including those from whom there are most results, show an increase in rate of tapping with bright light, and a decrease in dim light. One subject showed a slight, the other a more considerable, reversal of these results. In the case of this last subject, there is some evidence to suggest a special, somewhat morbid, peculiarity in this respect. For those subjects giving positive findings there was not only an increase under bright light, but a decrease under the dim light as compared with rate under the medium light. There was also no evidence of decrease of these positive findings through a semester; one subject, kept at the test for a year and a half with a view to obtaining evidence on this question, gave as positive results at the last as at the beginning.

It must be emphasized that the results from the two tapping periods, the first 45 sec. and the last 45 sec., have a very different significance as regards the possible effect of the lights. Any change in the first period, when the light had just been thrown on, might be due simply to a shift of attention, or some similar transitory element in the situation. The results from the last 45 sec. should be of much more importance, since the stimulus light has been on, by that time, some 12 min., and any effect then observed must be of some permanence.

As a matter of fact, the results are most distinctive in this last period. The group averages show greatest number of taps for the brightest light, and a regular and even decrease down to the least number for the dimmest light. When the groups are analyzed it appears, in the first place, that the two subjects who worked in both series agree substantially, in the indications they give under the two somewhat different conditions. In the first group of four (with four lights) all the subjects agree in showing most rapid tapping with the bright light, slowest with the dim. In the second group of five, three subjects give this same result. One, however, shows a slight, the other a fairly distinct increase with the dim light over the bright one. In this last case, introspection may throw some light on the situation. This subject (Mor.) was extremely fond of dim lighting. This was

due, he said, to a general liking for subdued light effects. He was fond of sitting in his room in the dark, or with the lights low, was very fond of candle-light, could think best when the lighting was dim. With the other subject giving opposed results there is no such clear-cut preference, though he did say once or twice that he could think better in the dark.

The results with the hues may be very briefly summarized. No differential effect of different hues, at equal brightnesses, upon rate of tapping appears. Two series were run, one consisting of red, yellow, green, blue, white, the other of red, green, blue. Eight subjects took part, five in the first series, four of these and three more in the second. It may be said, shortly, that no consistent findings appear with regard to any one of the hues studied. (See Table I.)

2. *The Effect of Color upon* (*a*) *Pulse and Respiration,* (*b*) *Estimates of Pressure, and* (*c*) *Judgments of the Pleasantness of Touch Substances.* It may be said at once that the work with pulse and respiration gave results which were entirely negative. The work was very carefully done; records were taken both at the beginning and the end of the color period, and studied with reference to both rate and shape of curve. But nothing appeared which could be correlated, in any way, with either brightness or hue.

The experiment of Stefanescu-Goanga,[35] already mentioned, was also largely repeated, with the writer's setting, but with negative results.

These negative findings are not, of course, proof positive of lack of any effect of hue or brightness upon the physiological processes. There may be an effect, and of a cumulative importance, on respiration and pulse. But the changes under such conditions must be, within the time any convenient measurement might extend (30, 45, or even 60 sec.) so minute as to be probably below the threshold of even the best technique.

It may also be said, with equal brevity, that results with the "pressure" and "pleasantness" tests were similarly negative. No influence of either brightness or hue, upon performance with these two tests, could be discovered.

The apparatus for the "pressure" test was simply an ordinary postage scale. For 1 min., during the 5 min. intermission between colors, the subject practiced pressing down exactly 16 oz., while looking at the dial. The scale was then taken away, but presented again, when the time during the color period came for the test; the subject was now given five trials at pressing down 16 oz. as previously practiced, but this time with the dial turned away from him. The record taken was the amount actually pressed at each attempt (the amounts pressed in the five trials being summed to make the "pressure" score for each color).

Just what function the test might be supposed to sample was not clear. Perhaps a bright light, or a red, if stimulating, would bring

about a more energetic push on the scale, and an overestimate. And a dim light might bring about less activity. But the fact was that no such relationships appeared. The test was interesting, but of no value, at least for the writer's experiment.

The experimentation with the touch substances was almost as simple and direct. A large variety of touch substances (different kinds of cloth, wood, metal, and so on) were fastened to small blocks of wood (one and one-fourth by two in. and one-half in. thick). Twenty of these blocks were put in a shallow box just big enough to hold them, five in a row with four rows. This box was covered with a hood of the heavy, unglazed drawing paper. When the time came for this test, the box was put on the table in front of the subject who, with his right hand, beginning at the upper left-hand corner, worked across the top row to the right. Each substance was felt in turn, and its pleasantness expressed on a scale of seven, where one was most unpleasant, four indifferent, and seven most pleasant. After the top row was finished, the subject dropped his hand to the next row, working from right to left; and so on till the twenty substances were all judged. The hood hid the substances from view, so that the subject had only a touch acquaintance with the materials.

After the test was finished the box was taken from the table, and the other tests given. During the intermission between color periods the experimenter, by a simple arrangement, completely and systematically changed the order of the substances. And from week to week the substances used were changed. The purpose in each case was to break up any memory of previous judgments on a particular substance, to make each estimate a product simply of the two present factors, the touch substance as it felt now, and the present affective attitude caused by the color. The results were handled by simply adding the values assigned to the twenty substances under each color, giving a total which might, perhaps, be called the affective level under the given light. The test seemed to the writer to have possibilities. But the findings were altogether negative. He still feels, though, that something of this sort might yield interesting data in a study of some other problem, to which it was better adapted.

3. *The Effect of Color upon Rate of Multiplying.* No study of this type would be complete without some sort of arithmetical test. Such tests seemed almost impossible of control sufficient for the purposes of the present problem. Little help could be obtained from previous work, since practically all tests previously used were ruled out, from the start, by the requirement that there should be no visual presentation. Nevertheless, the writer felt that an adequate study of his problem required at least an attempt at measurement of possible effects of color upon some such relatively complex form of mental work.

The test, as finally made up, consisted of multiplications of one-place by two-place numbers. Eleven such multiplications were given with each color; a test sheet, for a given day, thus consisted of three rows each having eleven problems. Three such sheets were prepared, enough for three weeks (or

a single series, where the colors came each once first in the hour). The three were then repeated in order. But the order of the colors was varied, so that any difference in difficulty of the different groups of eleven was distributed. The record was in time for each multiplication, as taken with a stop-watch, and in errors. In handling the material, that multiplication of the eleven which had the longest time was struck out; quite frequently a time would run much beyond the average as a result of some slight distraction; an elimination of the longest time of each eleven allowed, to some extent, for these variations. The times for the remaining ten were summed.

TABLE II

TIME IN MULTIPLYING (BRIGHTNESS SERIES) IN TERMS OF % OF AVERAGE TIME FOR HOURS

Four Brightness Series

Subject	I. (bright)		II.		III.		IV. (dim)	
	av.	m.v.	av.	m.v.	av.	m.v.	av.	m.v.
And	89	13.0	101	13.0	106	13.0	103	8.0
Dav	96	5.6	106	9.5	101	7.8	97	9.8
Fin	97	3.5	99	7.5	104	9.0	99	8.0
Kal	99	9.0	94	11.0	97	5.0	109	6.0
Average	95	7.7	100	10.2	102	8.7	102	7.9

(Ten hours each subject.)

Three Brightness Series

	I.		II.		III.	
And	100	6.2	99	4.7	101	5.6
Cur	95	7.6	101	10.0	104	7.6
Dav	99	4.9	99	4.8	102	5.3
Woolb	97	7.0	102	3.9	100	6.3
Mor	100	9.5	100	9.3	100	10.1
Average	98	7.0	100	6.5	101	6.9

(For each subject in order the number of hours is 10, 10, 8, 9, 9.)

TIME IN MULTIPLYING (HUE SERIES). IN TERMS OF % OF AVERAGE TIME FOR HOUR

Subject	Red		Green		Blue	
	av.	m.v.	av.	m.v.	av.	m.v.
Allp	99	4.7	101	6.2	99	8.2
La	101	4.4	102	4.5	97	2.7
Bul	100	8.3	99	7.9	100	8.8
Br	103	6.4	98	5.6	99	3.6
Cha	100	6.5	98	5.8	101	10.2
Woolb	98	7.5	104	7.8	97	12.0
Tul	103	4.4	102	6.1	95	6.0
Average	101	6.0	101	6.2	98	7.3

(Twelve hours three subjects, nine hours four subjects. m.v. after the group average is, for each table, the average of the m.v.'s, not the m.v. of the averages.)

The sets of eleven were made up to be as equivalent as possible. Any three numbers, as 6, 7, 9, can obviously be combined to form six problems of the type used: 6 times 79, 6 times 97, 7 times 69, 7 times 96, and so on. Five and a half such groups of six would, therefore, make up the materials for a day's test sheet: eleven problems with each of three colors. The problems were distributed among the three colors to give as great variety as possible, and as great uniformity: if 7 was used twice with a color as multiplier those two multiplications did not come together, and there were two sevens as multipliers with each of the other colors. In giving the test, the experimenter simply read each problem to the subject, slowly and distinctly, as "six times eighty-seven." The subject did the work mentally, and then replied with the answer, "five twenty-two." And the experimenter took time from the last syllable he said in giving the problem to the last syllable of the subject's reply.

In combining the results for a half year or more, two important factors had to be taken into account: (1) variations within the hour, and (2) variations from one experimental hour to another through the year. In dealing with practice through the year, some percentage statement of ranking of the colors, within the hour, was naturally suggested. The method finally adopted employed, as norm for the hour, the average of work under all three colors. The time under each color was then rated as a per cent of this.

For instance, suppose on a given day subject A's time for the ten multiplications, under each one of the three colors, ran as follows:

red	green	blue
55.0	57.2	59.2

these three would be averaged, giving 57.1., and per cents taken from this making a score of

red	green	blue
96%	100%	104%

Averages of these per cents through the year gave results free from practice effects from hour to hour. They were free from the many other variations from week to week, due to changes in condition, previous fatigue, and so on. Finally, the results from individual to individual were directly comparable; the average actual time for some individuals was over twice that for others.

The results are summarized in Table II. Mor., who gave results contrary to the tendency of the group in the tapping, does the same here. Otherwise there is a fairly consistent slowing with dim light, and acceleration of work with the bright.

The hue series gave no results so consistent. There is a suggestion of most rapid work with blue and slowest with green. But inspection of the individual averages reveals no consistent tendency such as appears with the brightnesses; minimum rate occurs three times in green, twice in red, once under blue, red and blue are once "tied for first place."

4. *The Effect of Color upon (a) Rate of Free Association, and (b) Immediate Memory for Nonsense Syllables.* The arithmetical work called for associational processes of a rigidly controlled and limited sort. As a contrast to this, it seemed interesting to try what the effect of color might be upon wholly uncontrolled, free association. Some test of memory also seemed necessary for a rounded test programme. Memory for nonsense syllables and rate in free association, under the various hues and brightnesses, were therefore investigated. And, it may be said at once, the results were entirely negative.

The materials and method for the free association test were substantially the same as used by Professor Langfeld in his study of the effects of prolonged fasting.[19] His lists of words, twenty to a list, were used, twenty words with each color. Timing was with a stopwatch. The experimenter simply read each word, slowly and distinctly, to the subject, who was instructed to reply at once with the first word that came into his mind. Time was from the last syllable of the stimulus word to the last syllable of the response. In handling the results, the longest and the shortest times were struck out, as most likely to contain extreme chance variations, the longest as perhaps due to a complex, the shortest as due, perhaps, to a mere perseveration from some previous word or associate. The total for the remaining eighteen words was then found.

The memory test was quite as simple. Immediate memory was clearly the only type which could be controlled adequately for the purposes of the experiment. Various kinds of material were tried; nonsense syllables were found to be the best suited to the test programme. Ten syllables were used with each color; a sample list runs as follows:

zok dib niv bam zek miz niz dop lor tem

In making the lists no long vowels were used (since these were found to "cling" in the memory more), and various other more usual precautions were taken, to make the lists of even and equivalent difficulty.

In giving the syllables they were read at a rate of two per sec., with a grouping in pairs by inflection of the voice. After the first reading the subject was asked to "give back" as many as he could. The list was then read to him again, and he was again asked to repeat all he could remember. This was done twice more, making four readings in all with each list. The syllables were scored as correct or half correct, in the recall; the final record was the sum of the recalls after each of the four readings. For instance, under red, the number of syllables given back after the first reading might be four, after the second five and a half, after the third seven, after the last eight. The record under the red would then be 24.5. The test was a great bore to the subjects, and yielded results of no value.

5. *The Effect of Color upon Rate of Continuous Choice Reaction.* A measurement frequently obtained, in work of this general nature, is speed in choice reaction. The writer felt strongly, however, that the classical reaction-time experi-

ment was neither suited for inclusion in his test programme nor calculated to get at the effects which were being sought.

It was at first planned to use the standard method, two stimuli and two keys, and the time in sigma for each separate reaction. But the technique was considerable; much time would be required to accumulate a small amount of data; and the measurements would be so minute that the appearance in them of so subtle an effect as the colors might be expected to have would hardly be likely. In fact, such investigation, with negative results, had already been reported.[23]

Besides, the writer had a feeling that the effect of a bright light, for instance, might consist not so much in an actual stimulation as in a "sustaining" of any activity which might be going on. Such an influence should show best on some form of rather monotonous work which could go on for an appreciable length of time in routine fashion; something comparable to work in a factory, where there are a few well understood stimuli and half-automatic responses, occurring over and over. Rivers[31] and Hollingworth[17] both used typewriting. Typewriting could obviously not be used in the present study; but something of this general nature, a continuous series of reactions to simple stimuli, was the type of task desired.

It finally occurred to the writer that instead of single reactions, and a time measurement of each, a continuous series, with timing only of the whole series, could be arranged; such a test would give exactly the sustained routine activity desired, and would also accommodate itself much more easily to the total test programme. The test, as finally worked out, may be briefly described. For signals two telegraph sounders were used; one, giving a sharp, loud click, to the right of the subject's table; the other, sounding duller and less loud, to his left. On the table, mounted on a small block of wood about 5 by 9 in. in size, were two keys, close enough together to be operated by the first and second fingers of the subject's right hand. The subject was simply to press the right-hand key when the right-hand signal sounded, and to respond with the other key to the left-hand signal. And the apparatus was so arranged that correct response on the part of the subject to a given signal automatically brought about the presentation of the next signal. But if the subject responded incorrectly, pressed the wrong key, no new signal appeared, and the subject had to rectify his mistake before he could proceed.

The test thus consisted of a continuous series of choice reactions, the subject setting his own rate and the apparatus exactly keeping pace with him, presenting new signals as fast as the old were reacted to. The test was run 4 min. with each color, 2 min. at the beginning of a color period and 2 min. at the end (taking the place of the tapping test, after work with the tapping test was completed, in the routine).

Highest possible speed on the part of the subject was not desired; he was told rather to work along steadily, much as he would in running a typewriter, and to emphasize accuracy rather than speed. Time was marked in 30 sec. intervals; both time and correct reactions were recorded by electric markers on a smoked drum. Only two choices were used, in order that learning might be easy and practice effects not great, and mistakes not over numerous.

The important, and original, feature of the test was, of course, the apparatus by which reactions and stimuli were thus interrelated. This interrelation was brought about by means of a special adjustment between contacts with each signal and with each key, and contacts on a revolving wheel. The wheel consisted of two brass cog wheels soldered together; bearing on the right hand wheel were the contact connecting with the right-hand signal and the contact connecting with the key to be pressed when the right-hand signal sounded, and bearing on the left-hand wheel were the contact to the left-hand signal and the contact to the key to be pressed when the left-hand signal sounded. The key contacts were side by side (that is, bearing on cogs which were side by side on the wheel); and underneath, making on the next cogs below, were the two signal contacts, also side by side, that is, making on cogs which were side by side. Certain cogs on each wheel were filed out, however, and these were so chosen that one, and only

TABLE III

NUMBER OF CORRECT CHOICE REACTIONS IN TWO MINUTES. IN TERMS OF % OF AVERAGE NUMBER, PER TWO MINUTES, FOR THE HOUR

Brightness Series

Sub.	I. (bright)				II.				III. (dim)			
	First 2′		Second 2′		First 2′		Second 2′		First 2′		Second 2′	
	av.	m.v.	av.	m.v.	av.	m.v.	av.	m.v.	av.	m.v.	av.	m.v.
And.....	100	2.0	102	6.9	100	8.5	104	8.9	95	7.4	98	7.6
Cur.....	98	5.5	102	5.0	107	5.2	105	2.8	91	8.3	98	7.1
Dav.....	103	4.1	99	3.3	100	4.8	99	4.5	101	4.6	96	6.6
Pep.....	101	2.0	101	4.0	101	1.0	100	4.0	99	2.0	98	4.0
Mor.....	99	4.2	99	5.9	98	5.2	102	3.9	99	6.2	102	3.9
Woo.....	97	3.4	101	2.5	100	5.9	100	4.0	98	2.9	103	4.3
Av.....	99	3.5	101	4.6	101	5.1	102	4.7	97	5.2	99	5.6

(Twelve hours each subject.)

Hue Series

Sub.	Red				Green				Blue			
	First 2′		Second 2′		First 2′		Second 2′		First 2′		Second 2′	
	av.	m.v.	av.	m.v.	av.	m.v.	av.	m.v.	av.	m.v.	av.	m.v.
Allp.....	100	2.9	102	1.7	100	4.6	103	2.0	96	4.7	99	2.1
Br.....	101	2.5	98	1.6	99	2.5	100	2.1	101	3.1	99	3.1
Bul.....	100	4.5	101	2.5	101	3.1	103	3.3	104	5.3	91	6.1
Chac.....	102	3.1	99	2.1	98	3.2	100	3.3	99	2.9	101	1.6
Tul.....	102	3.0	100	3.0	102	2.0	99	3.0	102	2.0	96	3.0
Woo.....	95	4.2	103	2.0	95	6.0	106	3.9	100	3.9	101	4.4
Av.....	100	3.4	100	2.1	99	3.6	102	2.9	100	3.6	98	3.4

(Twelve hours each subject.)

The m. v. in the average row is the average m. v., not the m.v. of the averages.

In handling per cents values up to .5% were dropped.

one, cog was presented at any given point. The result was that one, and only one, signal contact, and one and only one key contact, were making with the entire wheel at any given time.

Suppose, then, the subject responds (correctly) to a previous signal by pressing the proper key, thus closing the circuit, and suppose the right-hand signal contact is making with a cog on the wheel. The right-hand signal will be sounded. At the same time the current will go through a magnet, jerking forward a rachet to engage a succeeding cog on the wheel, so that when the subject breaks the circuit, by releasing the key, a spring action against the magnet will jerk the wheel around one cog's distance. The result will be that the cog which was making with the right-hand signal contact will now be making with the right-hand key contact. And only by pressing the right-hand key can the subject again close the circuit, and proceed further with the reaction series.

The essential feature of the device thus consists of this arrangement by which a given contact on the wheel makes successively with a signal and a key contact, so bringing it about that the reaction called for is the only one which can be completed.* The apparatus, which was mounted on a base about 4 by 12 in. (it could have been built half this size) and stood about 3 in. high, was in a sound-proof box under the experimenter's table. The cogs made in irregular order, so that the subject was given signals sometimes alternately right and left, again two or three in succession left or right, and in various combinations. After some five months of practice one subject began to learn the combinations; the connections were then simply reversed, and so all the combinations changed. Aside from this, there were no evidences of marked practice effects.

The results were first handled simply as total number of correct reactions in the first and the last 2 min.; this was taken as a measure of what might be called "reaction efficiency" under the given conditions. However, since individual differences, and variations from day to day, were marked these figures were converted into per cents of the average for the day, as were the times in the multiplication test.

It should be mentioned that 1 min. practice was given before the hour began; there was nevertheless evidence of practice effects through the hour, especially with certain subjects. And since no convenient way was found for eliminating such constant errors from the results

* The apparatus can be made to handle three, four or more choices, simply by using three, four or more cog wheels with their pairs of contacts. It can be used with any type of stimulus which can be electrically operated, and with any type of reaction. The arrangement would, therefore, seem of some general usefulness. The mechanism used by the writer was experimented with up to speeds about twice those of the average subject, and found perfectly accurate at such rates.

As has been pointed out to the writer by Prof. W. F. Dearborn, the test is somewhat similar to Seashore's "Psychergograph;"[32] the apparatus above described is, however, much more practicable. A mechanism very similar to the writer's has recently been described by McComas.[22]

they may be supposed to make the mean variation somewhat larger than it should be.

In the brightness series the group average shows "reaction efficiency" to be greatest under the medium light, least under the dim. As before, Mor. is an exception, and this time also Wool. Mean variations are also slightly greater under the dim light. Differences between first and last 2 min. periods are hardly consistent or definite enough to allow any significance to be attached to them; the two periods are probably best considered together. In the hue series the group average is least with blue; red and green show no important difference. It can hardly be said that in either series the results are of any significance, except in so far as certain subjects in the brightness series give findings in agreement with their previous records on the tapping and arithmetic tests. But this consistency would seem of some possible importance.

6. *The Effects of Color, as given in the Introspective Reports.* As has already been said, for the major part of the experimentation no introspection was called for. Introspection was obtained, however, for the first and last hours of each term, in order to study (1) group tendencies and the amount of individual variations in report, and (2) the effects of habituation to the colors. The tables are too complicated to present; the findings may, however, be briefly summarized.

In this work introspection in terms of the Wundtian tridimensional theory was called for.

This was done only after considerable hesitation. But more of a description than a mere indication as to pleasure value was wanted. And if each subject was left to form his own categories, tabular statement and cross-comparison would have been difficult. The subjects were therefore asked, for a time, to report on the colors as pleasant or unpleasant, exciting or depressing, tensing or relaxing. Two degrees of each quality were recognized; a color could be pleasant or it could be very pleasant, or it could be indifferent, neither pleasant nor unpleasant. The work was done with the four-color brightness and the five-color hue series, and was continued four weeks with the first and five with the second (making up on each case one "unit" where each color occurs once in each position through the hour).

The group totals show, for the brightness series, the two bright lights as most pleasant, the dim least. The bright lights are most exacting, tensing; the dim is most depressing, relaxing; indifference centers with the medium light. All of this was to be expected, except perhaps the pleasantness of the very bright light, which was not found unpleasant once in spite of its brightness. In the hue series, green was most pleasant, white next, blue most unpleasant. Red is most exciting and tensing, blue and white are most often called

depressing and relaxing. Judgments of indifference are rarest under red, showing that this hue is usually taken positively, one way or the other.

The variability of a given individual, from one hour to another, was considerable. For instance, And. reports the medium-bright light twice as very pleasant, and twice as wholly indifferent; Cha. finds blue three times exciting, once very exciting, once depressing; Bul. finds white tensing once, relaxing twice, indifferent twice; Lang. finds blue pleasant twice, unpleasant once, indifferent twice.

Individual averages also differ markedly. Bul. finds all the hues and all the brightnesses uniformly pleasant, with green and the brightest light each called very pleasant once. The dim light is for Fin. and Dav. uniformly unpleasant. Cha. finds red very pleasant, Ohl. very unpleasant. Red is for Bul. relaxing, for Dav. very tensing. The results of continued experience with the colors were quite what would be expected. There was a thinning of the feeling, a dropping-away of associative enrichment and toning, a matter-of-course attitude which paid very little attention to the colors one way or another.

Thus one individual, in the first weeks of his experience as subject, reported the bright light as "exhilarating, hard on the eyes at first, but less hard than the dim light," and later in the same period, "pleasant, more awake." The dim light was disagreeable, unpleasant, sleepy, tensing, bothering to the eyes. After three terms with the experiment he speaks of the bright light as "just an ordinary light, a bit pleasant when first turned on, doesn't mind it at all." And at the end of the period he says that there "is nothing special to report, slightly pleasant, that's all." Another subject reports in the first weeks that the bright light is "exciting, livening, like sunlight," the dim is "easy on the eyes, relaxing; doesn't feel like working." At the end of the year introspection on the bright light is simply that "the dirt spots on the paper show up more;" the dim light "tends to put to sleep, a little depressing."

Similarly, in the hue series, at the beginning of the year, a subject reports red "very pleasant, because of its richness," and again, "very pleasant, it is so rich." Blue is "pleasant, reminds one of the sky and clouds," again is "ghastly, unnatural, unpleasant, exciting" (this the following week!). At the end of the year blue is "neutral" and again "neutral in all ways." Red is "perhaps slightly pleasant" and again "slightly pleasant: it came as something of a surprise." Another subject who at first "didn't like the red a bit" and again found it "decidedly unpleasant, tensing, exciting," toward the end of the year called it merely "not quite so pleasant as the others," and "on the pleasant side." Blue was at first "very unpleasant, disagreeable, tiresome;" by June it had become "quite pleasant, rather restful," and again "quite pleasant, rather restful."

It may be said shortly that there is, if the introspective reports may be trusted, a definite decrease in affective reaction to both hue and brightness, with habituation.

The results obtained in the systematic experimentation may, then, be briefly summarized.

(1) Results with a tapping test, a multiplication test, and a continuous reaction test, suggest a decrease in function under dim, and an increase under bright light. With the other tests no effect of brightness was observable.

(2) The objective measurements showed no effect of hue, independent of brightness, upon the functions tested.

(3) Introspective estimates indicated marked variability, and marked individual differences, in the feeling-attitude toward brightness, and especially toward hue. A marked decrease in affective reaction to both hue and brightness, with habituation, is the only feature common to all the introspective reports.

IV. Summary and Conclusions

So much, then, for the writer's experimentation. It remains to evaluate these findings in the light of previous work, and to summarize what seem to be the most probable conclusions with regard to the problem.

First to be considered (1) are possible differences among the hues, in their effects upon mental and physical activity. As has already been intimated, the writer feels that there is no adequate evidence in previous work to show any such differences. He has found no such differences in the present experimentation. The common notion that certain hues have a marked influence upon emotional tone and mental work is the result, he believes, of such subtle and pervasive influences, arising from figures of speech, custom, artistic and social convention, and everyday association of certain hues to other sensations of a strong affective toning, as have already been mentioned in the historical review. The misconception may also be due in part to a failure to differentiate the influence of brightness from the influence of hue.

If there is an effect of illumination upon mental work, it would appear, then, (2) that brightness must be the important factor. Certain of the experimental results obtained by the writer have suggested a slowing of mental work under dim light and a stimulation under bright light. Such an effect is at least not incompatible with what little previous work has been done in this field; and the hypothesis of a stimulat-

ing or dynamogenic influence of brightness upon mental work and neuro-muscular tone seems by no means unreasonable. It need hardly be added that, if there *is* such an influence, it is a matter of great general importance, from a practical point of view.

It must, however, be emphasized at once that the writer's positive findings are few and far between, and that their reliability is by no means all that could be desired. The writer has argued that in such a study the interrelation of all the results should be taken into consideration, in judging of the significance of the findings. And he has based his conclusions on (1) the consistency of the results obtained from each subject on each single test, (2) the appreciable agreement among different subjects on the same test, and (3) the consistency of the results from test to test with each subject. But even with such a liberal basis of interpretation, it can hardly be said that the results do more than "suggest" the inferences which have been drawn.

It is also obvious that fifteen minutes of experimentation in a laboratory dark-room tell us little about what might be the effect of the same brightness continued throughout the day, in shop or schoolroom. Fundamentally, the problem is not a laboratory problem, and needs study of a larger sort, in schoolroom or shop. The present study can be thought of as contributing little more than a definition of the problem, and a suggestion of methods. But the writer is convinced that there is here a real problem in applied psychology, well worth more extended study.*

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* But not, let it be repeated, in the laboratory! The writer finds himself, after three years of intensive research with mental tests, going over this manuscript with oddly mixed feelings. Not so long ago he returned from a four days' visit to a city of about 11,000 population: during those four days, he personally tested every child of the 1,500 children in that school system. And in contrast, three years of weary, discouraged puttering in a dark room, with a total of twenty-six subjects! He would hardly think of basing any very serious conclusion, now, on less than that many hundred. But by all this he does not mean to imply a loss of interest in the older type of experimental problem. Rather he believes that practically all of the laboratory problems can be handled, in the large, by the "test" method, with such massed cases. He is convinced that recent developments in the field of group-tests are much more important for experimental psychology than is usually realized. The group-test is really, he believes, a new method, of splendid promise, applicable to the entire range of psychological investigation. And it is to the "group-test" that he looks for a final conclusive treatment of the majority of the older experimental problems: that is, a majority of those problems which may be worth such treatment!

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